

Protocol Activities

3.1 Annex I – Developing Cooperation in Rural Energy Development

The DOE and MOA signed Annex I, Developing Cooperation in Rural Electrification on June 27, 1995, as the first area of active cooperation and project development under the Energy Efficiency and Renewable Energy Protocol. The objectives of Annex I are to promote sustainable development in rural areas of China by accelerating the deployment of renewable energy systems, to demonstrate the technical and economic feasibility of these technologies for rural inhabitants, and to facilitate formation of links between the Chinese and U.S. renewable energy industries. The scope of the Annex allowed for, but is not limited to, work on:

- ♦ Biomass gasification/electric power generation at the village level,
- ♦ Medium and large-scale biogas plants,
- ♦ Solar photovoltaic and solar hot water heater technologies,
- ♦ Small wind turbines, and
- ♦ Small hydropower and micro hydropower systems.

To date, the major projects supported to date under Protocol Annex I include: (1) a solar home system project in Gansu Province; (2) provincial household surveys for market characterization and rural electrification options analyses in Inner Mongolia, Xinjiang, Qinghai, and Gansu; (3) a remote household wind/solar hybrid system project in Inner Mongolia; and (4) development of a national biomass resource data base for China with corollary assessments and analyses. Details of these project activities are given in the following sections.

3.1.1 Solar Photovoltaic and Wind Hybrid Rural Electrification Systems Technology Descriptions

Solar photovoltaic energy technology, called “photovoltaics” or “PV,” employs solid-state semiconductor devices with no moving parts, that convert sunlight into direct-current electricity. Wind energy technology uses turbines to convert the kinetic energy in the wind into alternating or direct-current electricity. These technologies can be used individually, or in hybrid combinations with diesel electric generators, or connected to the electricity grid.

Solar and wind resources are vast and widely available in most areas of China. Solar energy is the most widely available energy resource in the country, especially in the north and western regions and in coastal zones and on off-shore islands. If harnessed, solar resources could meet the entire Chinese electricity need. However, such large scale use is not economically practical today. Wind resources are also geographically diverse and abundant. This resource is discussed in more detail under Annex II, later in this report.

Projects under the Annex I Agreement have focused on deploying small solar and wind power systems for lighting, communications, micro-enterprise, refrigeration, and other similar low-power applications. As a result living standards and quality of life of rural populations have been substantially improved in the areas that previously had no access to electricity.

There is a large market for small-scale, off-grid wind and photovoltaic power generators in northern and western China, and for inhabited coastal islands. The World Bank estimated that in the five northern and

western provinces and autonomous regions of Qinghai, Tibet, Inner Mongolia, Xinjiang, and Gansu alone, there is a minimum of 2.2 million unelectrified households that are located in regions of China where grid power does not exist [11]. For more than 300 inhabited islands and potentially several thousand uninhabited islands which could be populated along the coast of China, the development of grid power in the near term is also not feasible. Renewable energy is one way to meet some of this need.

3.1.2 Gansu Province Solar Home System Project

Initial U.S.-China cooperation for rural electrification activities in China focused on the development of solar home system applications for western China. Generally, solar home systems in China for individual households start at 5 watts and can be 150 watts or larger. A typical solar home system in northwestern China consists of a 20 watt crystalline silicon PV module (Figure 2), a charge controller, a 38-ampere hour sealed lead-acid battery, two 8-watt compact fluorescent lamps, and necessary wiring. The retail price range of such systems is 1,800 to 2,400 RMB (\$219 to \$290 US), but the higher price systems are much higher quality and reliability. Many herdsmen and farmers can afford to buy these systems that provide light for children to read and study at night. Communication, via television and radio, is a prized addition and in some cases, a refrigerator and washing machine are purchased by more wealthy families [8].

The Gansu project is being implemented by the Solar Electric Light Fund (SELF) in Washington, D.C. and the Gansu Solar Electric Light Fund (GSELF) in Lanzhou, Gansu, and builds upon work previously conducted by these organizations. The objective of the project is to provide electricity to more than 600 remote homes and schools during the course of the project and to help to build an infrastructure for sustainable technology deployment. Technical assistance for capacity building includes: support for the



Figure 2. A typical solar home system in Gansu Province in western China

development of a distribution network for sales and service, a comprehensive training program, and experimental financing of systems through cash and credit sales. As of the fall of 1998, 320 systems had been installed in the joint U.S.-China project and another 275 systems had been installed by GSELF with the support of the Gansu Provincial government. In addition, ten 53-watt PV school systems using Solarex modules had been installed.

The lack of credit experience in rural China necessitates continued experimentation with installment credit terms to develop a functional credit system. The Gansu project is directed toward poor communities in rural Gansu, using limited subsidies that are being phased out during the course of the project. The province of Gansu has among the lowest annual income levels in all of China for remote farming communities. A revolving-fund account has been set up at the Lanzhou Branch of the China Construction Bank by SELF and GSELF to leverage the project by using customer receipts to purchase more systems.

The demonstration projects and infrastructure developed under this program are models for similar activities in other regions and government and private agencies throughout China. The State Council Office for Poverty Alleviation and Rural Development in Beijing is a key funding partner working closely with MOA. This Office has a primary responsibility for rural development projects in

China and spends more than \$1 billion (U.S. dollars) per year on rural infrastructure projects. The Gansu project is providing a mechanism for introducing the support of renewable energy technologies into the strategic planning activities.

A barrier to the widespread deployment of PV in China has been the variable quality of modules and balance-of-system components. Quality control was introduced through component testing and system monitoring during the Gansu project. NREL provided three PV modules previously calibrated under standard test conditions, for use as secondary testing standards in quality control protocols. Also, an extensive training program was included in the Gansu project to train users and installers and teach marketing techniques to village technicians and rural energy officers. The seminars taught basic principles of solar electricity as well as PV design, installation, and maintenance. As a result of the Gansu project, MOA is establishing a regional testing and training center in Lanzhou. MOA has rural energy offices in 1,800 of the 2,300 counties in China that could be involved in future projects.

3.1.3 Inner Mongolia Household PV/Wind Hybrid Systems Pilot Project

The Inner Mongolia Autonomous Region's (IMAR) government has been aggressive in developing renewable energy resources for both grid-connected and off-grid applications. Over the past 10 years, more than 120,000 households have been electrified with small wind generators in the range of 100 to 300 watts. In addition, more than 7,000 small PV systems (total of 120 kW) have been installed in remote households. However, there are still more than 300,000 remote households, 1,100 villages, and 198 townships that are unelectrified in remote rural regions of IMAR. By the year 2000, the New Energy Office of IMAR plans to install 25,000 remote household systems using wind, PV, and wind/PV hybrid systems and in the longer term a total of 80,000 systems throughout IMAR. The use of subsidies for rural systems is being phased out and commercialization based on market forces is being encouraged. The rural population of Inner Mongolia, consisting of herdsman and farmers, has among the highest annual income levels of the rural populations in China.

Annex I cooperation is assisting the New Energy Office of the Science and Technology Commission in Hohhot in the development and deployment of PV/wind hybrid household systems in Inner Mongolia. Other partners include the Inner Mongolia Polytechnic Institute, the University of Inner Mongolia, the Chinese Academy of Sciences in Beijing, the Shangdu Machinery Company in Inner Mongolia, and the JiKe Company in Beijing.

Renewable Energy Options Analysis – In the first phase of the cooperation in IMAR, the University of Delaware, NREL, and the Inner Mongolia team completed a levelized cost analysis of rural electrification options for several counties. The analysis compared renewable energy options with conventional gasoline engine driven generator sets based on local renewable resources and costs [10]. Beginning in 1995, NREL, the Center for Energy and Environmental Policy at the University of Delaware, and the Chinese Academy of Sciences in Beijing initiated a case study analysis of rural electrification options in IMAR. The project was conducted in cooperation with the Planning Commission and the New Energy Office of IMAR, which are the two key agencies responsible for renewable energy planning. Other participating organizations included the University of Inner Mongolia, the Inner Mongolia Polytechnic University, and several local companies.

The case study project involved levelized cost analyses of existing systems in four counties in the central and northern regions of IMAR, including Si Zi Wang, Su Ni Te You, A Ba Ga, and Dong Wu Zhu Mu Qin counties. Solar and wind resource data were collected from the four counties and performance/load data

were collected from 10 PV systems, 22 wind systems, and 6 PV and wind hybrid systems, which were in the 22 to 600 watt range. Two sizes of gasoline engine driven generator sets, common for household and ranch use, in the 450 to 500 watt range were evaluated for comparison.

The results of this first phase of the case study, the levelized cost-of-energy analyses, are shown in Table 1. For the types of systems currently being deployed for stand alone electrical generation in rural areas of IMAR, wind generators are the least-cost option for household electricity in the four counties. Small wind generators in the 100-, 200-, and 300-watt size range are manufactured locally in IMAR for the household market. The levelized cost of energy for small PV/wind hybrid and PV systems is higher than the cost of electricity generated by wind systems, but all of these renewable systems options result in a significantly lower cost of electricity compared to gasoline engine generator sets [7 and 9].

Study results show that designing optimized wind/PV/battery-storage hybrid rural household systems depend primarily on the local wind/solar resource mix and on the annual electric power demand for a given household-load. Normally, hybrid systems are more reliable and economical than wind or PV systems alone. The use of small wind/PV hybrid systems for remote-household electricity is attractive because of the complementary seasonal solar and wind resources.

The New Energy Office of IMAR and the Inner Mongolia Planning Commission are developing plans for expanding the use of wind/PV hybrid systems by remote herdsman's families for household electrification. NREL and the Center for Energy and Environmental Policy at the University of Delaware are providing technical assistance to these agencies in optimizing the design of such systems. Based on annual income levels, two types of systems are receiving attention. Hybrid systems in the 400 to 500 watt range are being developed to serve household loads that include lighting, a color television set and radio, a small washing machine, and a small freezer, requiring approximately 1.6 kWh per day of energy. Smaller systems in the 150 to 200 watt range are being developed for intermediate-income-level households that provide approximately 0.6-0.7 kWh per day for household loads that do not include a freezer or washing machine. A pilot

Table 1. Levelized Cost of Energy Values for Rural Electrification Options in Inner Mongolia

System	Output range (kWh/yr)	Levelized cost based on Mfr. quoted battery lifetime (\$/kWh)	Levelized cost based on battery lifetime from field analysis (\$/kWh)
Wind only	200-640	0.24-0.37	0.50-0.63
PV only	120-240	0.67-0.73	0.77-0.83
Small hybrids	400-750	0.31-0.46	0.57-0.72
Large hybrids	560-870	0.32-0.46	0.43-0.57
Gen-sets (not serving continuous duty cycle applications)	660-730*	0.76-0.80*	0.76-0.80*
Gen-sets (serving continuous duty cycle applications)	480-560	1.09-1.19	1.16-1.27

Source: University of Delaware. [10] *These estimates are based on systems configured without storage.

project based on remote-household hybrid systems is discussed below. The results of this pilot project will be fed into the planning process for the larger 25,000 and 80,000 remote-household projects by the IMAR government. A system monitoring component of the project will place data acquisition systems in several households to collect system performance data and solar and wind resource data.



Figure 3. 500-watt PV/wind hybrid household system in Inner Mongolia. *Courtesy of Wang Sicheng, JiKe Company.*

Pilot Projects for Home

Based Solar/Wind Systems—

Current cooperation with Inner Mongolia is focused on

completing the installation of 240 PV/wind home based systems during 1999. The typical demonstration system consists of: (1) a 100-watt wind turbine combined with 50-70 watts of PV or (2) a 300-watt wind turbine combined with 150-200 watts of PV, with battery storage. These systems are capable of delivering 0.6 kWh/day and 1.6 kWh/day, respectively, with high reliability. The systems provide energy for lighting, color television, consumer electronics, and some discretionary load. Systems of 450-500 watts (Figure 3) can also maintain a refrigeration load. Food storage by freezing is a major driving force for larger system development, even in colder climates. Summer is very hot in Inner Mongolia which borders on the southern edge of the Gobi desert.

An attractive option for household systems resulting from the analysis and prior research in Inner Mongolia is, PV/wind hybrid systems with battery storage. These systems are more reliable than PV or wind systems alone because of the seasonal wind and solar resources, with wind relatively more available in winter months and solar relatively more available in summer months. Analyses show that wind, PV, and PV/wind hybrid systems are lower-cost options for rural energy systems than fossil-fueled generators [7 and 9].

3.1.4 Expansion of the Solar Home System Project

Building on the successful projects in Gansu and Inner Mongolia, with technical and planning assistance from DOE and NREL, the MOA initiated a new 10,000 solar home system project in 1998. This will be conducted in six northwestern provinces and autonomous regions: Xinjiang, Qinghai, Gansu, Inner Mongolia, Ningxia, and Shaanxi. After the government restructuring in 1998, the implementation of this project has been transferred to local government authority. An additional impact of restructuring, was the transfer of the authority for managing Annex I activities in the MOA from the Chinese Department of Environmental Protection and Energy to the Department of Science and Education.

In parallel with the 10,000 solar home system project, a market characterization survey is being conducted in Qinghai and Xinjiang Provinces. Five counties were selected in each province for collecting data. All ten counties are also members of the National One Hundred Counties Integrated Rural Energy Development Program. The survey is designed to collect a statistical sampling of rural household data in each province

to characterize households in terms of socioeconomic parameters, including family size, income levels, potential electricity needs aimed at assessing willingness to pay for household systems. Technical data is also being collected on performance of operating rural electrification systems; electricity production; fuel consumption; wind; and solar, wind, and other meteorological data, to conduct rural electrification options analyses. Through the survey, the market potential for PV/wind home system applications in the targeted provinces will be better understood and the social and economic factors affecting the sustainable deployment of renewable energy technology will be evaluated. Finally, the priorities for PV/wind home systems development in northwestern China will be determined.

The Department of Science and Education in the MOA is responsible for the day-to-day work of the project. MOA established a steering team and an expert team for the project. The Department of Science and Education heads the steering team. Team members include personnel from the State Council Office of Poverty Alleviation and Development, the Center for Energy and Environment Protection under the MOA, and the heads of the rural energy offices in the six northwestern provinces. In the U.S., the University of Delaware, will be responsible for data analyses and assessments, in collaboration with the expert team in China.

The functions of the project steering team in China are to formulate measurements for completion of the project objectives; to provide guidance for the project; to coordinate the central and local government and institutional project participants; to ensure the successful implementation of the project; and to organize the necessary working meetings, training activities, and workshops. The Institute of Energy and Environment Protection under Chinese Academy of Agricultural Engineering chairs the expert team. The working team for the project includes national experts on PV and renewable energy technologies, economics, and local administration officials.

The survey and analyses will be completed by the end of 1999. The surveys also complement an expansion of the survey work done in Inner Mongolia and will be supplemented by a survey of the solar home systems and households installed in the joint project in Gansu.

3.1.5 Information Exchange Workshop

A workshop focusing on the use of small wind and solar-photovoltaic technologies for rural electrification in China was held on September 16-18, 1998, in Beijing. The workshop was jointly funded by the DOE, the Asia Pacific Economic Cooperation Program, and the Chinese MOA, with the assistance of the Center for Renewable Energy Development (CRED) in Beijing. The objectives of this workshop were to: (1) provide information to U.S. and Chinese businesses on rural electrification opportunities and plans for China, (2) provide a forum to facilitate networking of U.S. and Chinese company representatives, and (3) develop a strategy for fostering U.S.-Chinese joint venture and other business activity in rural and remote renewable energy electrification in China. The workshop was attended by over 70 Chinese and U.S. business, government, and NGO representatives. U.S. participants included: Solarex, Siemens, ASE America, EPV, USSC/ECD, Ascension Technology, SELCO, WINROCK, Bergey Wind Company, Atlantic Orient Corporation, and several rural electrification experts. There were more than 15 Chinese companies in attendance.

3.1.6 Biomass Systems – Technology Description

The use of biomass energy conversion technology can be categorized as direct burning, physical conversion, bioconversion, liquefaction, and solid waste processing technologies. Each of these classifications can

be further divided into particular processes shown in Figure 4. Research being done under Annex I of the Protocol is concentrated in three areas: technology for large and medium-scale biogas projects on animal farms, technology for thermolysis gasification of biomaterial such as agricultural residues, and on technology for the treatment of urban solid waste (garbage) [12].

Biomass resources are most extensively available and in use in the heavily populated regions in eastern and southern China. In 1996, about 220 Mtce, or 14% of China's total energy consumption came from biomass sources including wood, crop residue, animal waste, and other forms [12, Chapter 1]. Bioenergy use declined slightly from earlier estimates, as coal and electricity use increased. However, in rural areas biomass supplied 38% of overall energy consumption and 77% of fuel used on farms [14, Chapter 5]. In many parts of China, the biomass resource is sufficient to supply village-scale energy systems for both thermal and electrical energy.

There has been substantial growth in the agricultural sector in China. As the population grows there is need for more efficient and productive farming processes (if China is to remain a net exporter of food products). To date grain production has kept up with population growth [6]. Farm animal production has also grown dramatically. Examples of annual average increases are shown in Table 2. Agricultural growth is producing increased biomass wastes and resulting in an increasing demand for energy in the farming business sector. Improving standards of living are causing increased demand for many products. People in the cities are favoring lean pork and fresh eggs. Milk is no longer regarded as a luxury food. These trends are expected to continue, and resulting energy demand expansion and pollution will become more serious issues. [17]

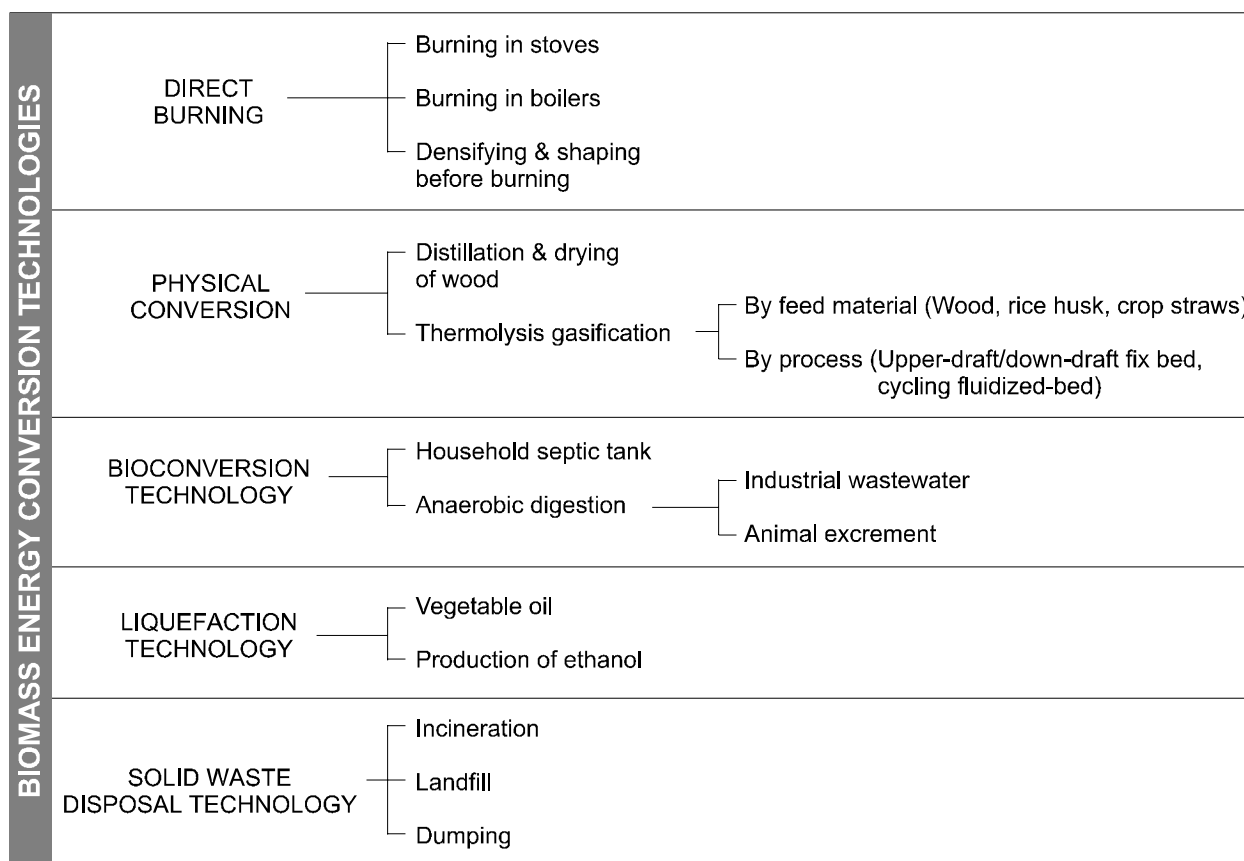


Figure 4. Categories of Biomass Energy Conversion Technologies

Table 2. Growth Rate in Farm Animal Production

	Annual Average Growth Rate (%)		
	1980-1984	1985-1989	1990-94
Cattle	4.7	3.8	6.5
Pigs	6.5	5.0	8.0
Chickens	20.5	19.8	22.9

Source: Chapter 2 in Ministry of Agriculture Report, Assessment of Biomass Resource Availability in China, 1998 [14].

The DOE, NREL, and the MOA are working together to evaluate the commercialization of biomass energy conversion technologies in the framework of a market-oriented development strategy. The initial phase of the cooperation involves assessing the market size, technology status, and the potential for biomass power projects in China. Information from phase one will then be used to formulate policies and design investment strategies, accelerating the pace of market-oriented development

and implementation of biomass energy technologies. Resource availability is being characterized by developing a database of the mainstream resources. These resources include agricultural crop residues, animal waste, sugarcane residues, fuel wood, and urban wastes. A geographic overlay at the provincial level, and at the county level in high potential areas, is applied to the resource data to create an initial GIS (geographical information system) database.

3.1.7 Biomass Resource Assessment

China has abundant biomass resources, fourth largest after coal, oil, and natural gas. The energy resource in rural agricultural discards (e.g. straw and stalks) is estimated to be 308 Mtce every year. Firewood resource is 130 Mtce. Together with animal excrement and city waste, the total biomass resource available annually is likely to be more than 650 Mtce, which is nearly half of the total energy consumption in China in 1995. [14, Chapter 1]

As much as 38% of the energy used in China's rural areas comes from biomass in the form of fuel wood, straws and stalks, and animal residues [12]. Most of this bioenergy is produced and consumed for the daily living needs of about 700 million rural inhabitants. However, as people's incomes rise, so does demand for "modern" fuels that are cleaner and more efficient for cooking and heating. It appears that current forms of biomass and bioenergy use will decline and the use of LPG and kerosene will increase. Modernization of biofuels would offset increasing rural area fossil fuel use, improve the environmental performance of biofuels, and retain incomes and jobs in rural areas [13 and 14].

Data from research and analysis of existing Chinese demonstration projects contains a wealth of information on bioenergy technologies. Technologies of special interest that are being studied under the Protocol agreement include: (1) biogasification technologies on a medium and large scale for combined heat and power, utilizing manures, (2) biogas technologies for treatment of urban solid wastes including landfill power generation, and (3) thermal gasification technologies for the integrated production of gas for cooking, industrial/community uses, along with combined heat and power the utilizing agricultural wastes. Case studies for major technologies at selected sites have been prepared that account for: (1) social, energy, environmental, and developmental strategies of selected project locations, (2) attitude and capacity of local government and inhabitants to support projects, (3) project financial and economic analysis, and (4) comparative analysis of grid-connected and stand-alone options for projects.

3.1.8 Biogas from Animal Waste Project

Excrement from animals can be processed in large anaerobic digester tanks to produce combustible biogas, fertilizer, and water emission. This process is shown in Figure 5. In China, during the 1970s and early 1980s, biogas plants were built on animal farms primarily to alleviate energy shortage in rural areas. Now, however, both the United States and China have significant environmental challenges as a result of intensive livestock production and industrial processes (e.g. distillery) that create high COD and BOD (Chemical and Biological Oxygen Demand) waste streams that often end up in rivers, lakes, and estuaries. This situation can deplete natural dissolved oxygen, resulting in algae blooms and negatively affect fishing and drinking water. The anaerobic digestion process can reduce the organic matter in the waste streams by up to 90%.

China has developed over 460 large scale anaerobic digestion units that produce 20 million cubic meters (m^3) of biogas annually, supplying 56,000 homes and 866 kW of electric power generation. Waste processing developments and the operating experience base are of potential interest in the United States. Consequently, an area of joint research is to determine the commercial viability of biogas production facilities. The modern production process is described in Figure 5. Animal fecal material is the primary input, with biogas, vegetable fertilizer, fish feedstock, grass fertilizer, and potable water as outputs.

One of the Biogas pilot projects is located at the Xinghuo breeding farm near Shanghai. This farm covers 22 km^2 and employs 6,600 people. The cow manure output is used to produce about 0.75 million m^3 of biogas annually, enough to meet the cooking and hot water needs of 3,200 households and 14 restaurants. This type of project may have numerous applications in the United States and around the world.

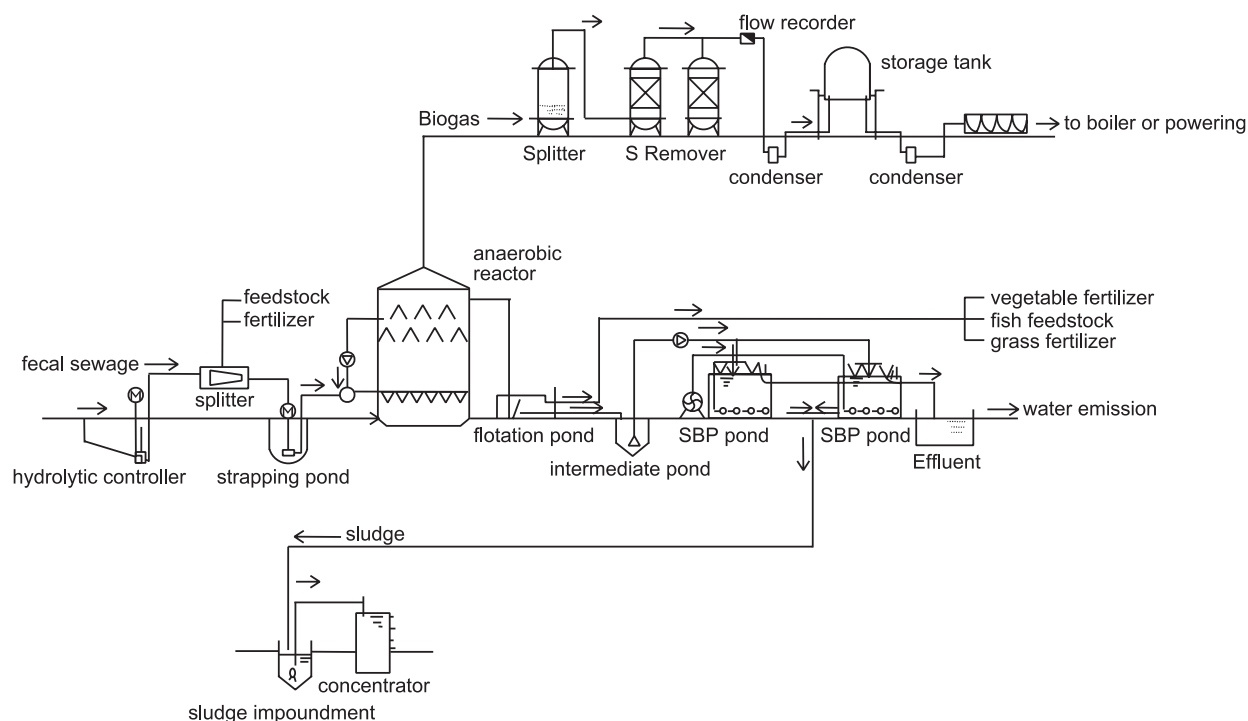


Figure 5. Flow Chart of Typical Animal Waste Biogas Demonstration Project

3.1.9 Biomass Gasification from Crop Straw Project

Co-firing of straws and stalks (Figure 6) with coal is an important area of cooperative research under this Annex. The increasing surplus of agricultural residues and their poor disposal by field burning is causing environmental problems. In provinces that have extensive coal fired electricity generation and also have large industrialized grain production such as Heilongjiang, Jilin, and Liaoning, the MOA has proposed that co-firing be investigated. Joint studies between MOA and NREL are expected to lead to pilot projects involving the power bureaus. Technical exchanges from similar projects in the U.S. are being conducted with China to evaluate project economics and technical issues.



Figure 6. Straw and Stalks Agricultural Residue.

Another approach is to convert biomass into gaseous fuel through a thermochemical gasification process. The basic principle is to heat biomass materials sufficiently to break the chains between organic carbon-hydrogen compounds with high molecular weight and decompose them to gaseous hydrocarbons with light molecular weight, such as carbon monoxide or hydrogen. This kind of conversion will change the biomass material into a form that can be used more conveniently. The product also has a much greater energy conversion efficiency than direct combustion of solid biomass. From Table 3, we can see the gasification features of various biomass

fuels and coal. Also, it is clear that coal is an attractive fuel with a much higher energy content in both solid fuel and gaseous forms.

There are three typical gasification techniques: distillation, rapid pyrolysis, and gasification. The first two are suitable for pyrolysis of wood or wood chips; the last is for gasification of stalks of crops such as corn and cotton. Because of the wide distribution of crop stalk resources, and the rapid increase in demand for clean, convenient rural energy, research is focused on gasification technologies [18].

Shandong Academy of Sciences developed crop stalks-based biomass gasification and centralized gas-supply system technology. In this process crop stalks are converted into combustible gas with low caloric value in a down-draft, fixed-bed gasifier, then the particulates and tar are removed from the gas, and finally the gas is delivered to households as living fuel for cooking through centralized gas-supply system in a range of village units. See Figure 7. After more than 10 years of research, currently there are four demonstration systems operating successfully in Dongpan, Zhangsan, Tengzhai, and Xunjia villages. Each village system includes a crop stalk-based gasifier set, key equipment for a centralized gas-supply system, gas pipeline facilities and their customers, household gas stoves, etc. After the first demonstration sites were made operational in pilot villages, a total of 14 sets of gasification equipment have been disseminated for use and are currently running in Shandong Province. This kind of gasification system with a scale of 100-200 households is also being demonstrated in other areas, including Beijing.

Table 3. Gasification Features of Various Fuels.

Fuel type [1]	Fuel features				Gasification intensity	Gas production	Heat value of gas
	Humidity (%)	Ash content (%)	Size (millimeter)	Heat value (MJ/m ³)	(kg/m ² -h)	(m ³ /kg)	(kJ/m ³)
air-dried wood	25	1.0	80-100	13,600	200-250	2.2	4,273
wood wastes	23	1.0	sawdust	13,600	260	2.3	4,360
wheat stalk and rice straw	10	3.5	cracked	14,700	180-220	2.3	4,690
cowpat	16	6.0	50*50	11,700	200-230	2.2	3,908
leaves	10	5.0	natural size	13,800	200-230	2.0	3,694
coal (washed Pennsylvania Bituminous)[2]	6.5	6.5		24,300		2.0 [3]	12,300 [3]

Source: [1] *Biomass energy conversion technology*, Northwest University Press (Xian: China), 1993.

[2] *Mechanical Engineers Handbook*, Editor M. Kutz, Wiley Interscience, 1986.

[3] *Perry's Chemical Engineering Handbook*, McGraw Hill, 1984.

3.1.10 Biogas from Municipal Refuse Landfills Project

Landfills are different from natural dumps. The natural dump is used to dispose of refuse in wastelands or ditches without any cover or scientific disposal. Natural dumping was used in many cities in China prior to the 1980s. The disadvantage of this technology is obvious. Due to exposure of the refuse to air; bad odors, flies, mosquitoes, and mice proliferate ruining the ecological system near the dump site and endanger public health. Meanwhile, percolating water, heavy metals, and other harmful pollutants decomposed by microorganisms from refuse seep underground and pollute water resources.

Landfill disposal is a mature technology, developed to reduce environmental problems by preventing secondary pollution while producing combustible gas. Biogas from landfills can be collected by pipeline and used for power generation or chemical production. At present, 4,817 landfill plants have been built world wide and are producing more than 5.1 billion m³ of biogas annually, equal to 2.4 million tons of crude oil.

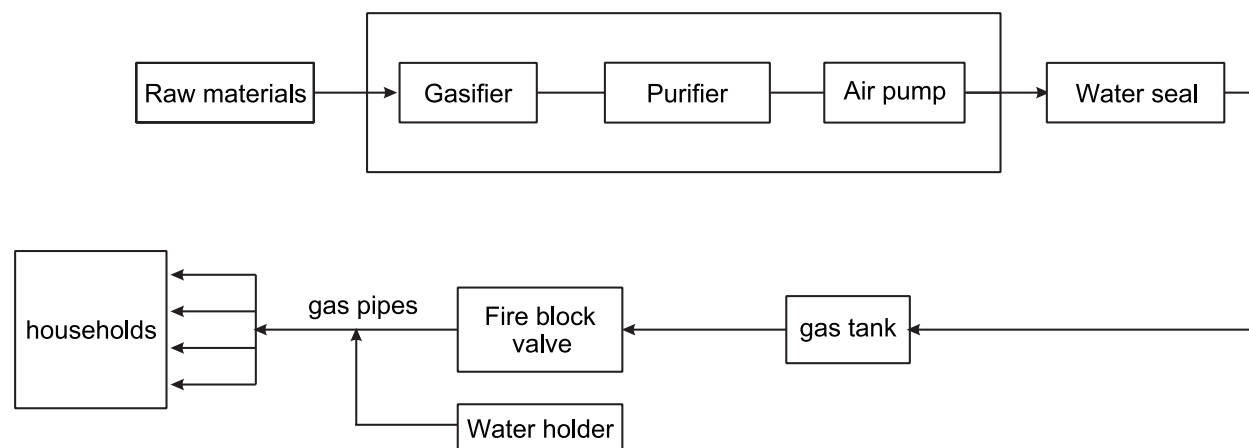


Figure 7. Configuration of Biogasification and Distribution System Demonstration Project

Landfill is just one of the municipal refuse disposal technologies. Incineration is another process. Each method has its own advantages and can be applied in different situations. Landfills are popular in many countries because they are simple to operate, low cost, and suitable for various kinds of refuse and energy recovery.

One of the goals of the research under Annex I is to help China introduce landfill technologies and to solve technical and secondary pollution problems. Specific research efforts are aimed at reducing land area requirements, improving efficiency and reducing leaching as follows:

- ♦ Raising the height of landfill plants to save land and decompose refuse faster, producing biogas;
- ♦ Adopt new materials and technologies to strengthen the under-pile impervious barrier and by installing a sewage disposal system to prevent pollution to water resource;
- ♦ Pipeline shaft drilling, pipeline construction, and condensed water removal;
- ♦ H₂S control;
- ♦ Refuse leaching solution and biogas collecting pipelines are built to increase the biogas collecting efficiency; and
- ♦ Compacting the refuse to prevent air from entering the refuse and avoid aerobic reaction.

In general, along with the improvement of landfill technology and more operating experience, landfill technology is maturing and information is being disseminated through the Annex activities on the following technical topics:

- ♦ Collaborative research, technical assistance, and scientist exchanges and
- ♦ Technical publications and conferences.

The Chengdu Institute of Chinese Academy of Science is the leading organization developing landfill technology in China. Their accomplishments include: completing the research of biogas production from refuse anaerobic osmosis for 1985-1986, research of municipal organic refuse systematic disposal during 1987-1990, and a 160 m³ pilot-scale test. More recently, “harmless landfill” projects are being constructed. Eight have been completed are in operation.

The use of landfill biogas is playing an increasingly important role in power generation. Combustion equipment consists of internal combustion engines or turbines. Otto cycle internal combustion engines and diesel engines are most commonly used. Gasifiers can be added to provide properly mixed gas to the combustion engine for use in the landfill plant.. Gas turbines and steam turbines are also being applied in some plants. The advantage of a gas turbine is its large output per unit weight, about 70-140 kW/ton, much higher than 27 kW/ton for internal combustion engine and 10 kW/ton for steam turbines. Internal combustion engines are lower cost however, and are used more in China while turbines are used more in landfill plants in the U.S. In China, some small internal combustion engine generators are portable and are moved from one landfill plant to another.

Landfill research and development taking place in China is focused mainly on internal combustion engine applications. Efforts are aimed at developing simple modifications for gasoline and diesel engines that can potentially be manufactured in China as biogas engines. Although some landfill plants are successfully operational in China, the landfill technology is generally very small scale. Research to date concludes that the engine type used in landfill power projects will depend on the biogas production. Internal combustion engines are suitable for capacities from 1,000 to 3,000 kW; if the needed capacity exceeds 3,000 kW, gas turbines, with higher efficiency, are a better choice although they are more costly.

3.1.11 Village Scale Biogasification Power Projects

A major focus of the ongoing bilateral cooperation, is the use of biomass at the village level for electricity production. One system that is being evaluated in detail consists of a thermal gasification unit that delivers low calorific value cooking gas directly to households. This biogas, which is cleaned and cooled for distribution, could also be used in efficient engines to generate electricity. One concept being evaluated is the use of a Sterling motor at around the 25 kW output level. With technical assistance from NREL, three case studies are being performed in three provinces in detail, including Zhejiang, Shandong, and Sichuan. A techno-economic analysis of a gasification project using crop straw to produce cooking fuel at the village level has been completed for Shandong, resulting in demonstration projects funded entirely by the Chinese in 10 villages with an additional 24 being planned.

3.1.12 Reports

Three major bilingual reports have been published as a result of the bilateral cooperation for resource assessment in China, including:

- ♦ “Assessment of Biomass Resource Availability in China,” [14]
- ♦ “Biomass Energy Conversion Technologies in China: Development and assessment,” [12] and
- ♦ “Design for Market-oriented Development Strategy of Bioenergy Technologies in China,” [15]

A CD-ROM has also been produced containing a complete national biomass database developed during the cooperative effort, entitled: “Evaluation of Commercialization of Biomass Energy Conversion Technologies and their Market Oriented Development Strategy.” These information products are available from the NREL and MOA.